# Competing localization of vortices

## Scientific Achievement

We investigated a Bose system with long range interactions in the presence of disorder. Formation of the bound states at strong impurity sites gives rise to a depletion of the superfluid density. We predicted an intermediate superfluid state where the condensate and localized bosons are present simultaneously. We found that interactions suppress localization and that with the increase of the boson density, the system experiences a *delocalization transition* into a state where all bosons are delocalized. We mapped our results onto a 3D system of vortices in type II superconductors in the presence of columnar defects; the intermediate superfluid state maps to an intermediate vortex liquid state[where an unpinned vortex liquid co-exists with the pinned vortices. We considered a model which can be solved exactly - $N$ vortices competing for the pinning site at a single columnar defect - and find that in such a system, the depinning behavior is a true phase transition. We predicted the *depinning transition* within the vortex liquid state and a new kind of vortex lattice melting: *depinning induced melting*.

## Significance

This work breaks new ground in the quantitative description of localization effects in disordered Bose systems. This is a rapidly developing area which resonates nicely with the current research of BEC confined in a finite potential trap. Our approach allows for investigation of novel pinning effects in the vortex liquid state. In particular, we plan to investigate the effect of weak localization of the vortex liquid by columnar defects. The results of our investigations were published in: A. V. Lopatin and V. M. Vinokur, Phys. Rev. Lett. **92**, 067008 (2004) and J. Kierfeld and V. M. Vinokur, Phys. Rev. Lett. **94**, 077005 (2005).

## Performers

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# Competing Localization of Vortices

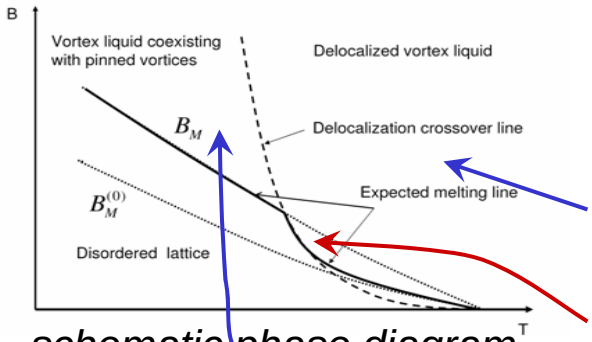
## Theory

$$\hat{H} = \int d^2 r \psi^+ \left[ p^2/2m - \mu + U(r) \right] \psi + \int d^2 r_1 d^2 r_2 \psi^+(r_1)\psi(r_1)\, V(r_{12})\, \psi^+(r_2)\psi(r_2)$$

Effective model that describes occupation of the localized sates:

$$\hat{H}_{eff} = \hat{b}_1^+ (E_1 + \alpha - \mu)\, \hat{b}_1 + \beta(\hat{b}_1^+ + \hat{b}_1)$$

cccupation number: $n = \hat{b}_1^+ \hat{b}_1$




*schematic phase diagram for the vortex system with columnar defects*

crossover from occupied to non-occupied state at n=1/2

$$B = \frac{\Phi_0 \kappa^4 T^2}{(\Phi_0/4\pi)^4 \ln(\lambda/\ell_\perp)} \exp\left(-\frac{T}{T^*}\right)$$

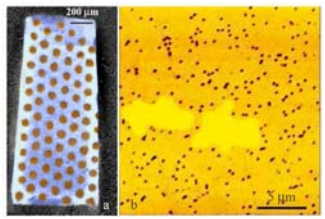
Above the transition correlations in z direction disappear: liquid of vortex segments

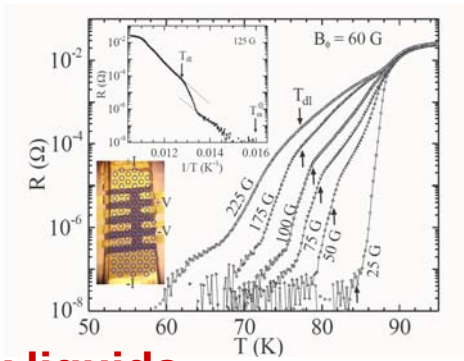
**Delocalization-induced melting of the vortex lattice**

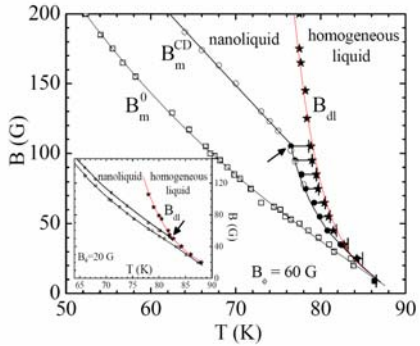
Below delocalization line correlations restore: vortex line liquid

## Experiment

Zeldov group at Weizmann Institute






## Future plan: weak localization of vortex liquids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